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Spectroradiometric measurements of tree species in the Caspian forests of Iran

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SPECTRORADIOMETRIC MEASUREMENTS OF TREE SPECIES IN THE CASPIAN FORESTS OF IRAN

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ABSTRACT:

Forest type maps play a significant role in sustainable forest management. For many years aerial photos and satellite data were a primary data source supporting forest type mapping. Recent developments in remote sensing provide opportunities to further enhance forest type maps by introducing variations of spectral, biochemical and biophysical properties at various scales. A structural sampling and collection of the above variables will support an improved interfacing between spatially continuous data, forest type maps and finally will support forward and inverse modeling of advanced forest biochemical, -structural, and other relevant variables.

The main objective of this study is to acquire, process and analyze spectral signatures of main forest tree species of the Caspian forest (namely *Fagus orientalis*, *Quercus castaneifolia*, *Carpinus betulus*, *Alnus subcordata*, and *Parrotia persica*) located in the Research Forest owned by the University of Tehran on the Northern slopes of the Elburz mountains, Iran. We have sampled 102 spectra each of the afore mentioned tree species using leaf 'pile' reflectance and branch pile reflectance. We build a comprehensive database of leaf optical properties, and other measures such as branch and twig reflectance. Field spectroradiometric measurements (350-2500nm) were carried out in the course of summer 2007. Spectral measurements were acquired in altitude gradients between 400-2100m (low, mid and high elevation) of the Elburz mountains. All spectral signatures after preprocessing were analyzed physically and statistically. We select a set of vegetation indices related to optical properties of the leaves and exploit changes of vegetation reflectance signature dependent on illumination conditions (shaded vs. non-shaded leaves) and chlorophyll content. We conclude that the Vogelmann index (R_{740}/R_{720}) is more sensitive to chlorophyll content in comparison with the other indices. It shows that hornbeam (*Carpinus betulus*) is significantly different in spectral signatures compared to beech (*Fagus orientalis*), oak, (*Quercus castaneifolia*) and alder (*Alnus subcordata*) as well as ironwood (*Parrotia persica*) with alder and oak being statistically different ($p < 0.0001$, $\alpha = 0.01$). Variability in spectral properties related to tree age and exposition is also assessed. We conclude by presenting a comprehensive spectral database of leaf optical properties of the main dominant tree species for further use in the determination of photosynthetic and non-photosynthetic fractions, remote determination of dominant species, radiative transfer based on forest modeling, and ecosystem change analysis (invasive species, etc.).

1. INTRODUCTION

The Caspian forest belongs to the broadleaf deciduous biome, which is widely distributed from North America to Europe and Asia. These forests receive considerable precipitation, between 750 and 2,200 mm per year. The Caspian forest contains the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the science or conservation point of view of with a significant ecological value.

In recent years contemporary with developing new satellite data, numerous studies have been performed to prepare forest type maps of the north of Iran by multispectral data, but their results did not indicate high overall accuracy (Shataee et al., 2004; Latifi et al., 2006; Darvishsefat et al., 2003). Because of the mountainous and complex micro topography condition as well as high diversity in these forests, it needs high spectral and spatial resolution for an accurate type map. There is a strong optimism that with the arrival of the new generation of imaging spectrometers (hyperspectral data), significantly higher quality data will be available. Spectroradiometry has advantages over conventional techniques to map forest type, allowing the non destructive sampling of objects and enabling users to gain critical

information more quickly and cheaply. In recent years many researchers have studied the spectral characteristics of species and have prepared spectral libraries that are necessary for providing reference spectra for a number of procedures in remote sensing, e. g. spectral unmixing (Kneubuehler et al., 1998; Schaepman & Dangel 2000).

Leaf optical properties are influenced by the species-specific structure of the leaf surface and the concentration of chlorophyll and other biochemical constituents, water content, and leaf structure (Asner, 1998; Jacquemoud & Ustin; Stimson et al., 2005). Many optical vegetation indices have been investigated related to biochemical compositions in leaf and canopy level to investigate the spectral differences among the species (Blackburn, 1997; Lovelock & Robinson, 2002; Maire et al., 2003; Clevers et al., 2005; Malenovsky, et al., 2005).

The scope of this study was to acquire spectral signatures of the most important tree species of the Caspian forest namely *Fagus orientalis*, *Quercus castaneifolia*, *Carpinus betulus*, *Alnus subcordata*, and *Parrotia persica* and to assess the spectral reflectance differences among the afore mentioned tree species using vegetation indices (VIs) related to chlorophyll content. This information is necessary for

classification and forest type mapping using hyperspectral images.

2. MATERIALS AND METHODS

2.1. Study sites

The test site for this study is located in the research Forest of University of Tehran located in Mazandaran province in the north of Iran, which is a part of the Caspian forest (figure .1). This forest is divided to seven districts with a total area of 845 ha.

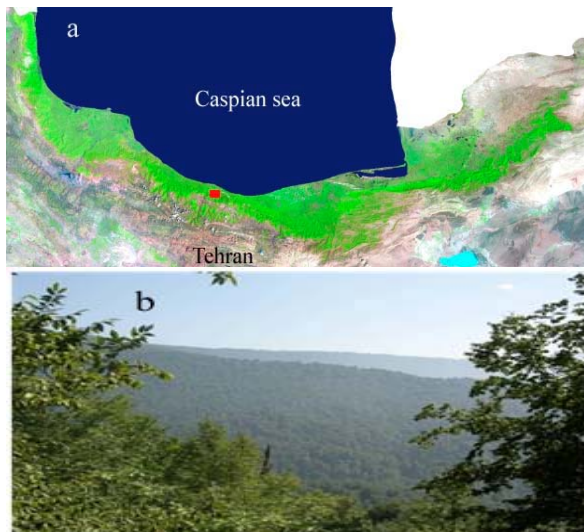


Figure 1: study site location in the Caspian forest (a), the photo of mountainous view of the Caspian forest in study area

2.2. Sample collection

Species	Alder	Hornbeam	Beech	Ironwood	Oak
No. of trees sampled	19	20	29	15	19
Altitude(m)	750-1250	700-100	400-2200	400-590	700-1320
DBH (cm)	38-61	35-68	40-70	28-36	42-70
Height (m)	27-36	15-25	25-38	15-22	35-60
Branch level: (3R ¹ *2S ² *2E ³ *N ⁴)	228	240	348	180	228
Leaf level: (3R*2S*2E*N)	228	240	348	180	228
Twig:(6R*N)	120	120	174	90	114
Branch: (6R*N)	120	120	174	90	114

¹R, number of repeats or cut branches ²-S, leaf surface, adaxial/abaxial- ³ E, exposed, illuminated/shaded- ⁴N, number of tree sample for each species

Table 1: The attribute table of number of each species and some measured characteristics

To sample a representative set of different types of leaves, branches were harvested in two exposed conditions, illuminated and shaded leaves, at various levels ranging from the upper to the lower position in the canopy. A total of 2448

spectrum for leaves from 102 samples of five tree species were analyzed. The samples were collected at three sites in altitude gradient between 400 and 2100 m (low, mid and high elevation) in August and September 2007. For each species the samples were chosen from dominant-stairs trees in different DBH (diameter at breast height). Table 1 shows the attribute table of number of each species and measured characteristics.

2.3. Spectroradiometry measurements

Reflectance measurements were done using a ASD Fieldspec Pro spectroradiometer (350-2500 nm) in the course of summer 2007. The sensor, with a field of view of 25°, was positioned 30-40 cm above the samples at nadir position. Prior to each three measurement, a white reference panel with approximately 100% reflectance was used as a reference standard. The measurements were conducted under clear and cloudless sky between 10:00 and 14:00 at local time. For each tree individual three branches have been cut in shade and sun exposed condition. At first, the spectral measurements of branch-leaves pile has been done and after removing the leaves, spectral leave pile was acquired from adaxial and abaxial surfaces.

2.3. Methods

Vegetation indices

A variety of indices related to total chlorophyll changes were used to characterize complex spectra and make comparisons possible among species and between illumination conditions. These indices have been derived from the list that Maire et al. (2004) presented based on knowledge of the reflectance properties of chlorophyll content described in other literatures. Total chlorophyll is correlated with the red edge position which is the wavelength λ (in nanometers) of the maximum slope of the reflectance spectrum at wavelength between 690 and 740 nm. The depths and widths of pigment absorption troughs and the position and magnitude of reflectance peaks can be quite different among species (Ustin et al. 1993).

Vegetation index	Equation	Reference
mND ₇₀₅ : modified Normalized difference	$(R_{750} - R_{705}) / (R_{750} + R_{705} - 2R_{445})$	Sims & Gamon 2002
Simple Ratio	R_{750} / R_{700}	Gitelson et al 1996
mSR ₇₀₅ : modified Simple Ratio	$(R_{750} - R_{445}) / (R_{705} - R_{445})$	Sims & Gamon 2002
Vogelmann index	R_{740} / R_{720}	Vogelmann et al 1993
Datt index	$(R_{850} - R_{710}) / (R_{850} + R_{680})$	Datt 1999

Table 2: Vegetation indices used to estimate chlorophyll content at leaf level.

Variations in chlorophyll content can be caused by structural status of the leaves, atmospheric pollution, nutrient deficiency, toxicity, plant disease, and radiation stress (Filella & Peñuelas 1999, Clevers et al., 2005). Although these factors influence the chlorophyll content within the species or individual trees we hypothesized that the chlorophyll changes

between the species is more than within them. We calculated these vegetation indices listed in Table 2, that are based on the chlorophyll absorption band in the 680- 850 region of the spectrum.

Statistical analysis

The differences between sunlit and shaded leaves in each species were tested by comparing the mean of vegetation index values. We also used Analysis of Variance (ANOVA) to test the differences among the species both in sunlit and shaded leaves. Statistical analyses were performed with SAS software.

3. RESULT AND CONCLUTIONS

3.1. Spectral fingerprinting of forest species

The sampling plan in acquiring spectral measurement is very important to get a reliable spectral library. Because of large altitude gradient in the Caspian forest and complex topography as well as uneven aged stands we sampled the species in different diameter from dominant stairs to cover the variety of the spectral signature between different samples.

The spectra of the collected species show the typical pattern of vegetation (Figure 2). A visual discrimination of the species by their reflectance alone must be regarded as difficult for most species. Figure 2 shows the mean spectra of all five species in two illumination conditions. Although we could distinguish that sunlit leaves shows less reflectance values for some species verse shaded leaves, it must be statistically tested to prove the differences between them.

In order to remove the noise spectra in water absorption feature wavelength we calculated the standard deviation of all reflectance values in each wavelength and omitted the values which were more than twice of standard deviation (Figure 3). Since a non-noisy reference spectrum does not exist, we focused on those wavelengths that had values less than twice of standard deviation.

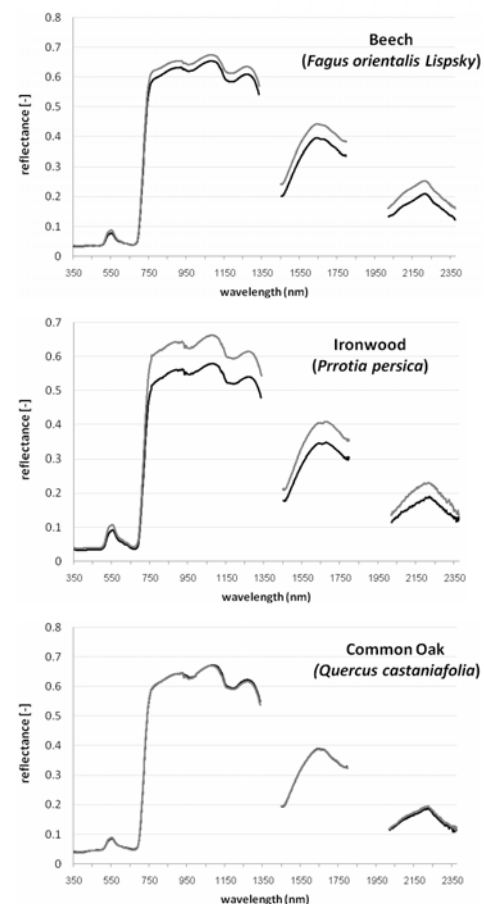
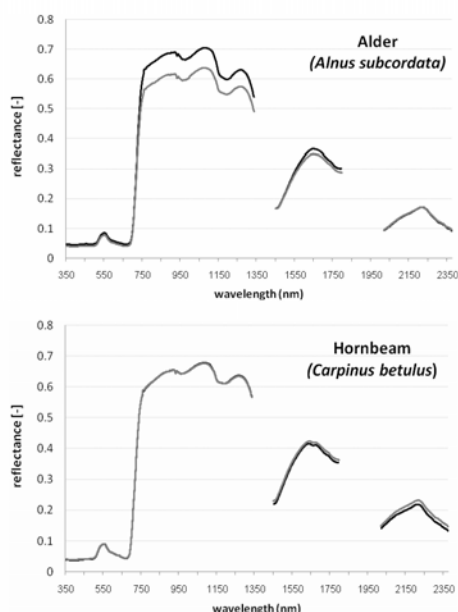


Figure 2: Spectral fingerprints of five tree species in two exposed conditions (shaded vs. sunlit leaves). Black lines represent sunlit leaves and gray line shaded leaves.

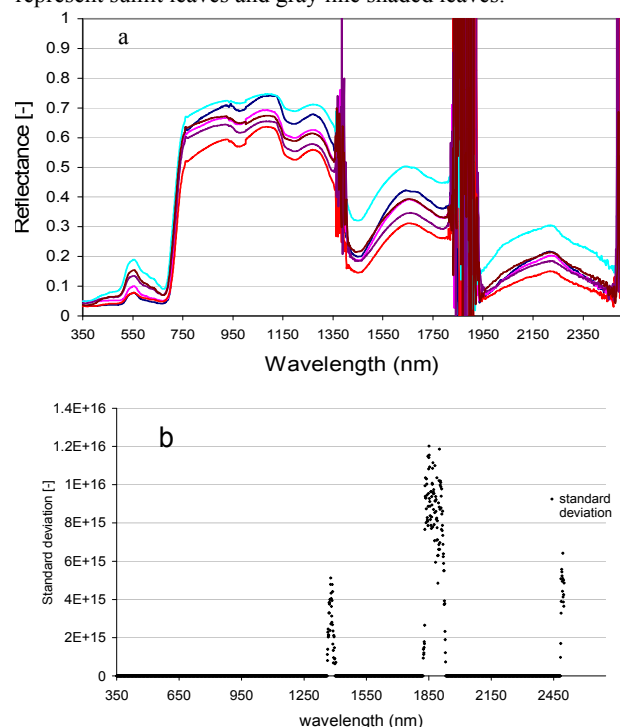


Figure 3: Standard deviation (b) calculated for all reflectance values in each wavelength to remove the noise spectra in water absorption bands (a).

3.2. Statistical analysis

Although there were some differences between sunlit and shaded leaves in absolute values of reflectance across the spectrum, we just focused on wavelength that related to chlorophyll content changes by using some indices. All indices listed in Table 2 are tested statistically for both illumination conditions for each species and different chlorophyll content among the species. Based on statistical results (Table 3) we can see that some indices are partly able to differ the shaded and sunlit leaves (Table 3). None of the vegetation indices shows significant difference for Ironwood and Hornbeam. Except for the mSR index all indices are sensitive to changing chlorophyll content of beech in illumination condition ($p < 0.0001$). The illumination effect was significant at $p < 0.0001$ for alder and oak by using mND and Vogelmann index (R_{740}/R_{720}).

Species Vegetation index	Alder	Hornbeam	Beech	Ironwood	Oak
mND ₇₀₅	**	NS	**	NS	**
mSR ₇₀₅	NS	NS	NS	NS	NS
Simple ratio	NS	NS	**	NS	NS
Vogelmann index	**	NS	**	NS	**
Datt index	**	NS	**	NS	NS

Table 3: T test result to investigate the differences between the index values for shaded and sunlit leaves. **: significant differences; NS: no significant differences ($\alpha = 0.01$).

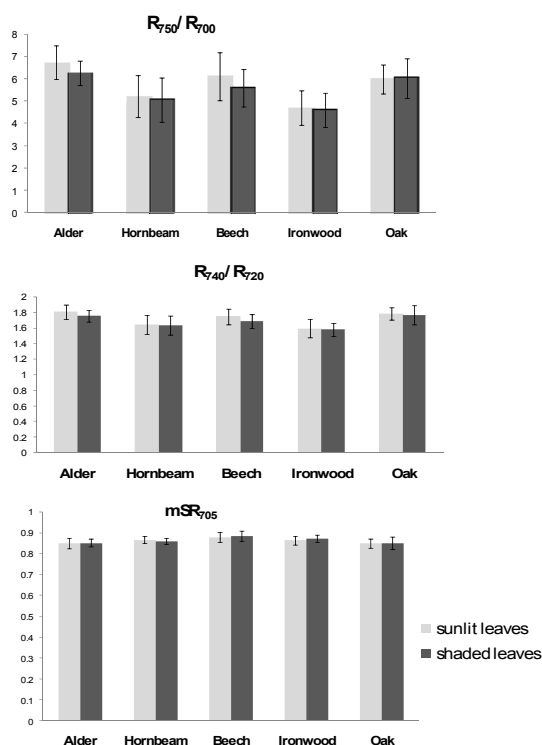


Figure 4: Comparison of sensitive indices (R_{750}/R_{700} and R_{740}/R_{720}) and non sensitive index (mSR₇₀₅) to chlorophyll content in each species in different illumination condition and between all five species to illustrate different behaviours.

One-way analysis of variance was used to test statistically significant differences between species, both in sunlit and shaded leaves individually for those species that were significant in two exposed condition. The results show that the Vogelmann index (R_{740}/R_{720}) and simple ratio (R_{750}/R_{700}) used by Gitelson et al. 1996, are sensitive to chlorophyll content changing in different species (figure 4). Vogelmann index shows that hornbeam is different with beech, oak and alder as well as ironwood with alder and oak ($p < 0.0001$, $\alpha = 0.01$). Beech and ironwood is statistically difference for sunlit leaves. There is no significant difference for any of the species in shaded position. Simple ratio index (R_{750}/R_{700}) is also sensitive to the chlorophyll difference between some of the species such as hornbeam with alder and ironwood with alder, beech and oak for sunlit leaves. Differences of Shaded leaves of hornbeam and ironwood, hornbeam and oak as well as ironwood and oak were significant. However mSR and mND indices showed different chlorophyll contents in the study of Sims and Gamon (2002), in this study we reached poor result compared to simple ratio indices. Maire et al. (2004) tested more than 60 published chlorophyll indices on the experimental and simulated data base, they could reach good result by using the Vogelmann index and the Gitelson and Merzylak index for different forest tree species that confirmed our results.

Our results highlight the importance of considering the illumination condition in canopy for those species that are especially present in dominant stairs and have more distinct shaded and sunlit leaves such as beech, alder and oak. This result is derived just by considering chlorophyll content as an important pigment in plant and could indicate that the other pigments that contribute in photosynthetic process might change in different exposed conditions. The strong relationships of the VIs with some biophysical parameters such as LAI can be somewhat expected in those VIs which are sensitive to chlorophyll absorption feature that is related to LAI.

However, even though very important, leaf optical properties alone are not sufficient to unambiguously spectrally distinguish tree species. Also other canopy components such as branches, twigs, bark and understory need to be measured. The detection of statistically significant differences in intraspecific reflectance associates with illumination, leaf surface, non photosynthetic components such as twigs, branches and bark as well as habitat of sample collection suggest a potential for updating monitoring forest type maps and assess further the distribution of mixed forest stands. This study has produced the first spectral library of the most important forest tree species of the Caspian forest taking into account the range of spectral variability expected for the species measured under natural illumination conditions. The results provide a sound basis for mapping tree species in the north forest of Iran and beyond.

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